Study on the evaluation of outdoor thermal comfort for elderly people: a case study of Chengdu, China

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ABSTRACT

Population aging has become a prevalent global phenomenon. Comfortable outdoor spaces can promote good health for the elderly. This paper aimed to investigate the effect of environmental parameters of hot summer and cold winter climate area on outdoor thermal comfort for the elderly during summer, transition season, and winter. Two urban parks in Chengdu, China, were selected as the research sites. Microclimate measurements and subjective thermal sensory questionnaire was administered to 602 participants. The thermal sensation, thermal neutral physiological equivalent temperature (PET), and comfort PET range were calculated and analyzed. The associations between thermal sensation and environment parameters were explored by using regression model. The following results can be concluded. (1) Elderly are more sensitive to the thermal environment in summer than in winter. The mean radiation temperature (Tmrt) is the most important variables for elderly in summer. While in winter the relationship between thermal environmental parameters and thermal sensation was not significant. (2) The outdoor neutral PET is 24.56℃, 16.78℃ and 15.01℃ in summer, fall, and winter, respectively. The neutral PET is higher than that of elderly in cold climate area. (3) During summer, old adults preferred a lower Tmrt and higher wind speed. In fall, old adults preferred higher humidity and lower air temperature.

Keywords: Hot summer-cold winter climate region, urban environment, public health, elderly, outdoor thermal comfort

1. INTRODUCTION

In China, population aging is steadily increasing alongside urbanization. By 2040, the number of people aged over 60 years old will rise up to 402 million[1]. This demographic shift may result in numerous economic and social challenges. Consequently, both developed and developing countries have become increasingly concerned with the study of older age groups[2]. However, old people are more vulnerable to thermal risks associated with outdoor activities due to their physical fragility. Exposure to high temperatures for long time may lead to higher core temperatures for old people. Additionally, it is less likely for old people to take preventative measures to thermal environment as they exhibit low thermal sensitivity to environmental changes[3]. Therefore, it is necessary to evaluate the effect of environmental parameters on outdoor thermal comfort conditions of elderly.

Recent research has revealed that human thermal comfort is not only influenced by climatic conditions, but also by the geothermal adaptation and cultural differences of the population. Firstly, people's subjective thermal preferences vary according to their geographic location. Secondly, the subjective sensation of temperature and thermal comfort can also differ among different gender and age groups living in the same area. Finally, non-meteorological factors, such as the surrounding landscape, can also influence the subjective thermal sensory status of a population. In summary, these studies underscore the importance of thermal adaptation in thermal comfort research.

In regions of China with similar climate characteristics to Chengdu, several studies have been conducted on thermal comfort for old people. Studies conducted in Chongqing showed that elderly tend to natural ventilation and environments instead of artificial cooling to enhance their thermal sensations[4]. In Shanghai, some studies found that old people have a lower perception on the outdoor environment than younger people[5]. A study carried out in Scotland demonstrated that older populations exhibit lower sensitivity to wet conditions in comparison to younger populations[6]. Another study conducted in Lhasa showed that, older age groups have a preference for higher levels of solar radiation in winter and lower wind speeds throughout the year[7].

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Hence, in order to further develop a comprehensive understanding of the outdoor environment of the elderly in hot summer and cold winter climate zones. This study aims to investigate the outdoor thermal perception of the elderly in Chengdu. The objectives of the study are as follows:

(1) To investigate the thermal sensation characteristics of old adults in Chengdu.

(2) To analyze the comfort PET and the effect of environmental variables on thermal comfort.

2. MATERIALS AND METHODS

2.1 Study site

Chengdu city, situated at the western periphery of the Sichuan Basin, has a sloping topography in the northwest-southeast direction. Chengdu located in the hot summer and cold winter climate zone (HSCW) of China. Generally, the Chengdu area experiences mild winters and high temperatures in the summer months, with relative humidity remaining high throughout the year. This study was conducted in Jinsha Binjiang Park and Xipu Binjiang Park in Chengdu. Three survey points were selected as the study site. Two measurement points in Jinsha Binjiang Park, one at the pavilion in the center of the park and the other at the riverside walkway. The third measurement point was located at the riverside in Xipu Binjiang Park (Figure 1).

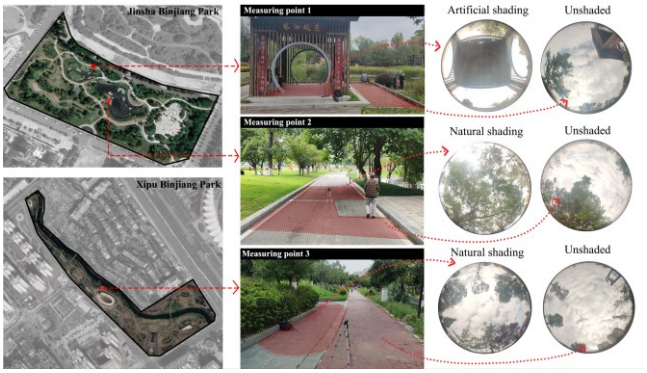

Figure 1. Location and photos of measurement points.

2.2 Data collection

The experiment was conducted between July and December in 2021. The experiment included field thermal parameter measurements and subjective questionnaire. The thermal environment parameters measured in investigation included air temperature (℃), air relative humidity (%), wind speed (m/s), and solar radiation (w/m^2). The measure equipment for these environment parameters met the standards of International Organization for Standardization (Table 1)[8]. The instruments were placed on both shaded and unshaded environment at test point.

The subjective questionnaire was conducted in the park. The elderly who suffer from diseases or take medicine were excluded from this study. Subjective feeling voting (i.e. thermal sensation voting (TSV), solar feeling voting, thermal comfort voting (TCV), moist feeling voting and wind feeling voting) was conducted in this study. Thermal comfort voting was assessed using the ASHRAE 4-point scale, and other factors were presented using ASHRAE 7-point scale[9]. The subjects who have been outside for at least 30 minutes were invited in the study and they were required to stand or sit at the test point for 5 minutes before completing the questionnaire. A total of 602 questionnaires were distributed, and 563 effective questionnaires were collected, with an effective rate of 93.52%.

Table 1. The information of instrument.

Instrument	Temperature and humidity recorder GPS958	Solar radiation recorder Spn1	Universal thermal comfort recorder zp150
Accuracy	±3%RH, ±0.5℃	±5% ±10 W·m^{-2}	±3% wind speed, ±0.2℃
Recording frequency	Every 1 min	Every 1 min	Every 1 min

2.3 PET calculation

Physiologically equivalent temperature (PET) was chosen as the indicator for evaluating thermal comfort, as it was commonly used in previous studies[7]. The mean radiant temperature (Tmrt) is a crucial parameter for PET calculation. The calculation equation of Tmrt is as follows:

$$T_{mrt} = [(T_g + 273.15)^4 + \frac{1.1 \times 10^8 V_a^{0.6}}{\varepsilon D^4} \times (T_g - T_a)]^{1/4} - 273.15 \quad (1)$$

where *Tmrt* denotes the mean radiation temperature, T_g represents the black sphere temperature, T_a represents the air temperature, V_a represents the wind speed, D represents the diameter of the black sphere in meters (the standard black sphere used was a diameter of 0.15 m), and ε represents the emissivity of the black sphere (ε=0.95).

Python in conjunction with IBM SPSS 25.0 was used to analysis the data. Spearman's correlation analysis, and regression analysis were employed to process and derive the mathematical model. Then, the thermal neutral temperature and thermal comfort temperature ranges for elderly was obtained according to the model.

3. RESULTS

3.1 Objective meteorological parameters

Table 2 displays the meteorological parameters in different seasons measured from three observation points. Overall, the meteorological characteristics of measurement points were consistent with the climatic features of Chengdu. The variation ranges of wind speed in summer and fall were much greater than in winter. The average solar radiance and its variation range was clearly greater than in fall and winter. It is worth to be noted that the range of thermal parameter of Chengdu in summer was much greater than in fall and winter.

Table 2. Outdoor thermal environment parameters in different seasons.

Thermal environment parameters	Season	Mean	Max	Min	SD
Air temperature	Summer/fall/winter	34.52/20.33/11.68	38.4/25.2/13.7	29.9/16.5/9.4	1.74/1.71/1.07
Black globe temperature	Summer/fall/winter	36.53/22.82/11.86	46.4/32.2/13.3	30.9/18.1/10	3.04/3.07/0.89
Relative humidity	Summer/fall/winter	52.76/62.35/63.18	76.3/87.1/72.9	43.6/48.8/54.5	6.08/6.85/5.91
Wind speed	Summer/fall/winter	0.43/0.55/0.42	1.92/1.5/1.1	0.09/0.13/0.13	0.43/0.3/0.21
Solar radiance	Summer/fall/winter	218.23/177.4/116.61	681/349/200	20.0/34.0/49.0	129.68/78.35/38.79

3.2 Subjective thermal response

3.2.1 Subjective feeling vote. The results of thermal feeling vote were compared to see whether there is a significant difference among different seasons. (Figure 2). Compared to summer and winter, the elderly were easy to get neutrality of thermal sensation, wind sensation, and solar sensation in fall. The old adults were likely to feel moist sensation neutrality in winter. To be specific, 67.7% of the elderly felt slight hot to very hot, 30% of elderly felt neutral in summer. In winter, 35.3% of elderly felt slightly cold, 60.7% of elderly felt neutral. In terms of solar feeling vote, 81.1% of the elderly felt slightly shaded to very shaded on winter. 75.1% of the elderly felt neutral to slightly sun. Overall, old adults were likely to get solar neutrality in summer, while they were likely to get thermal neutrality in winter.

3.2.2 TCV and TSV. A binomial fit was employed to study the association between the thermal comfort vote (TCV) and the thermal sensation vote (TSV). According to Figure 3, a strong relationship existed between TSV and TCV. The regression model revealed that old adults in Chengdu could not achieve the state of a TCV=0. The elderly felt the minimum TCV was 1.14 in summer, corresponding to a TSV of -1.03; 0.54 in fall, corresponding to a TSV of 0.04; and 0.62 in winter, corresponding to a TSV of 0.71. Overall, old adults in Chengdu were easy to be in a comfortable state in winter than in summer.

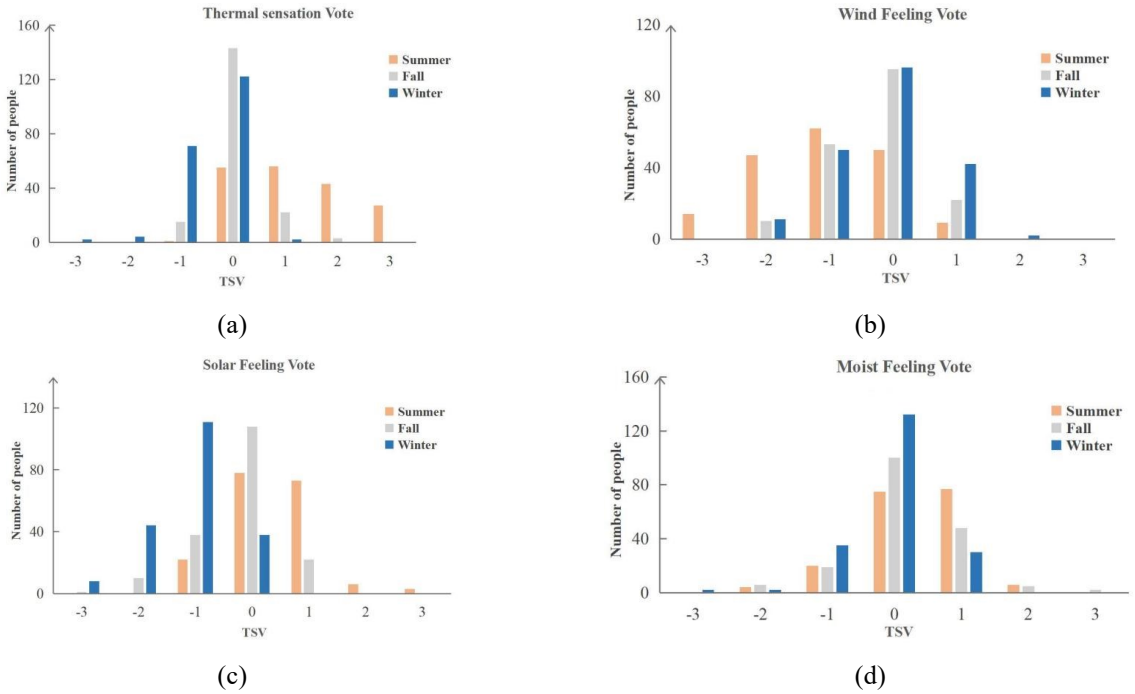

Figure 2. Subjective feeling vote. (a): Thermal sensation vote; (b): Wind feeling vote; (c): Solar feeling vote; (d) Moist feeling vote.

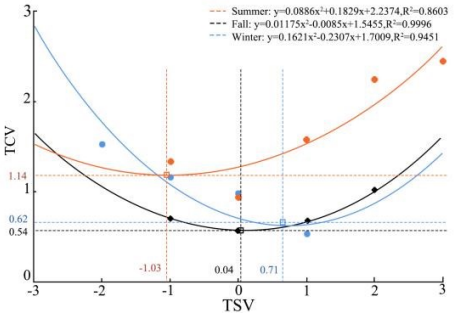

Figure 3. The fitted relationship between TSV and TCV.

3.3 Thermal environmental parameters and TSV

Spearman rank correlation coefficient was employed to analysis correlation between TSV and thermal environmental parameters (Table 3). Based on the statistical analysis, older people perceive the thermal environment more strongly in summer than in winter.To be specific, all environment factors strongly correlated with subjective thermal sensation in summer. Among these parameters, the Tmrt is the most important parameters for old adults in summer. The elderly preferred a lower Tmrt and higher wind speed in summer. In fall, humidity, air temperature, and Tmrt were correlated with thermal sensation. The Humidity is the most sensitive to thermal sensation. The elderly felt more comfortable with a higher humidity. While the association between thermal environmental parameters and thermal sensation was not significant in winter.

Table 3. TSV correlation with other subjective.

Season	Thermal environmental parameters			
	Wind speed	Relative humidity	Air temperature	Tmrt
Summer	-0.304**	-0.272**	0.180*	0.356**
Fall	0.118	-0.318**	0.304**	0.154*

Season	Thermal environmental parameters			
	Wind speed	Relative humidity	Air temperature	Tmrt
Winter	0.127	0.007	-0.022	0.019

Note: ** means the probability of irrelevance is less than 0.01, * means the probability of irrelevance is between 0.01 and 0.05.

3.4 Evaluation of thermal sensation

3.4.1 PET. Figure 4 displays the trend of TSV and PET for different seasons. As TSV increases, the value of PET increased and then decreased. The turning point of TSV is 2, 1, and -1 for summer, fall, and winter, respectively. Overall, the number of samples with TSV=-1 and TSV=0 increases gradually in winter and summer as the PET value increases. Therefore, as PET increases, older adults felt warmer.

3.4.2 Neutral PET and comfort zone. Neutral temperature means the temperature that people feel is not too cold or too hot[9]. Previous processing method[10] was employed for this study. The weighted mean TSV corresponding to PET at 1° C was obtained and then it was used to construct a regression model with PET. The regression equations of the TSV and PET of elderly people in different seasons are as follows:

There was a strong relationship between TSV and TCV (Figure 5). From the regression model, it can be seen that TSV in summer is the best fitted to PET, with an R^2 of 0.8, and the worst in winter. This may be due to the fact that the PET values in summer span up to 20°C, whereas in winter, the temperature is low throughout the day, making the winter PET span only 5°C. TSV=-0.5-0.5 represents the PET comfort range, while TSV=0 represents neutral PET. From the above equations, the comfortable PET range was 20.73–29.39℃, and neutral PET was 24.56℃ in summer. In fall, the comfortable PET range was 10.15-23.28℃, and neutral PET was16.78℃. In winter, the comfortable PET range was 6.82–23.21℃, and neutral PET was 15.01℃.

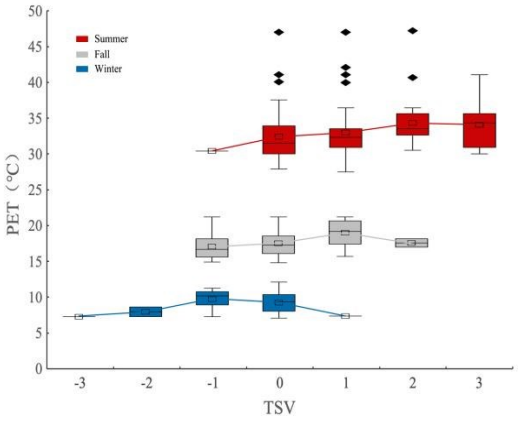

Figure 4. The trend of PET and TSV.

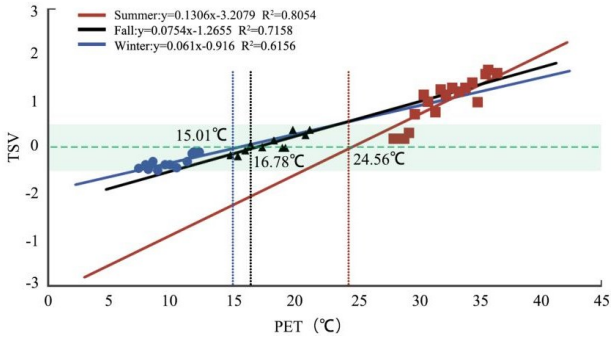

Figure 5. Linear relationship between PET and TSV

4. DISCUSSION

Through the above study, we have analyzed the characteristics of subjective heat sensation of old adults in Chengdu, including correlations between their thermal perception and meteorological conditions. Furthermore, we derived thermal neutral PET and comfortable PET range for old adults in different seasons.

As presented in Table 4, the difference of neutral temperature and its range of old adults in different climatic zone was significant. The thermal neutral PET of summer and winter in Chengdu is higher than in cold area. Moreover, older adults have a wider thermal neutral range in summer and winter than in Madrid. Experiments conducted in Mianyang, which was geographically and climatically similar to Chengdu, showed that elderly in Chengdu experience higher thermal comfort in summer compared to younger people. While elderly in Chengdu experience lower thermal comfort than young in winter.

Table 4. Comparison of thermal comfort for different age groups under similar climatic conditions in China.

Climatic zone	Region	Age	Neutral PET (summe/winter)	Comfort PET Range	
				Summer	Winter
Cold[a]	Xi'an[11]	Elder	20.3/12.76	-	-
Csa[b]	Madrid[12]	Elder	-	23.89-28.31	18.49-21.51
Hot summer and cold winter[a]	Mianyang[13]	Young		18.22-28.7	15.83-29.7
	Chengdu (this study)	Elder	24.56/15.01	20.73-29.39	6.82-23.21

Note: a: Climatic regionalization of China; b: Koppen climate classification.

5. CONCLUSION

An investigation of outdoor thermal sensation for elderly was conducted in Chengdu, which included field measurements of meteorological parameters and questionnaire survey. According to the statistical analyses of thermal sensory characteristics, PET and correlations between thermal environmental parameters and thermal sensation some conclusion may conclude:

(1) Elderly are more sensitive to the thermal environment in summer than in winter. The Tmrt is the most important parameters for old adults in summer. The Humidity is the most sensitive to thermal sensation in fall. While only wind speed was correlated with thermal sensation in winter.

(2) The outdoor neutral PET of old adults is 24.56℃, 16.78℃, and 15.01℃ in summer, fall, and winter, respectively. The neutral PET is higher than that of elderly in cold area. The comfortable PET range of elder is higher than that of young in the same climate area during summer and winter.

(3) During summer, old adults preferred a lower Tmrt and higher wind speed. In fall, old adults felt more comfortable with a lower humidity.

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